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Dominant height growth and site index curves for Calabrian pine (*Pinus brutia* Ten.) in central Cyprus

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A dominant height growth model and a site index model were developed for Calabrian pine (*Pinus brutia* Ten.) in central Cyprus. Data from 64 stem analysis in 32 temporary plots, where Calabrian pine was the only tree species, were used for modeling. The plots were selected randomly in proportion to two site types. Four difference equations were tested. The evaluation criteria included qualitative and quantitative examinations and a testing with split data. The difference equation of Korf showed the best results for all data. An analysis of the height growth patterns among sites - as these were defined from the selected equation - was made in order to study the behavior of different site index curves. Results indicated the validity of a common height growth model for the two sites. In spite of the irregular height growth pattern observed in Calabrian pine, the model obtained allows us to classify and compare correctly Calabrian pine stands growing at different sites.

Contents

1. Introduction

The species *Pinus brutia* Ten. (Calabrian pine) is a characteristic species of the eastern Mediterranean [12,26,27,34,64,83]. *P. brutia* is widely extended in Turkey and far Eastern Greece, secondarily in the Crimea, Caucasus coast, Azerbaijan, Iraq, Syria, Lebanon, Crete and Cyprus [54].

It is an important species for multi-purpose forestry; construction, industry, carpentry, firewood and pulp [7,10,61]. Additionally, its post-fire regeneration ability makes it a unique forest species within the fragile Mediterranean ecosystems [68].

P. brutia generally occurs in the Mediterranean-type climate of hot and dry summers and mild and rainy winters. This species occurs most abundantly in the semi-arid and sub-humid zones [64]. The species has strict rainfall requirements, being absent from the arid bioclimatic zone and rare in the lower semi-arid zone, but widespread in the humid zone [63]. We find Calabrian pine in zones with a mean annual precipitation between 400 and 2000 mm [36,45]. *P. brutia* is well adapted to the Mediterranean-type climate in several physiological and morphological characteristics and is a drought resistant species [17,19,33,44,45,53]. The adaptabilities of its provenances to drought vary [32], but *P. brutia*

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generally achieves its optimum growth in rainy regions of more than 900–1000 mm mean annual precipitation. Its typical elevation range is between 0 and 1500 m above sea level [45]. The geographical isolation among populations implies the existence of several races, with different ecological characteristics and behavior [54].

Calabrian pine is a fast growing tree species; its mean annual increment in plantations can be over 10 m^3/ha (at a spacing of 4.5 m^2; 2222 trees per hectare, site class I, site index 20 m) between the ages of 25 and 35 years [35]. New stands of *P. brutia* generally begin after fires, although it can also naturally regenerate without fire [26,27,46,47,48,76,77]. Several adaptations greatly contribute to its post-fire regeneration [20,46]. Seedlings develop rapidly growing tap roots while the stems grow comparatively slowly in height, so that seedlings can have 65 cm tap roots within five to six months after germination [26,27,46]. Early stem growth is greater at higher elevations, while average root growth is the opposite [77]. The early rapid growth of *P. brutia* continues during the following years; the mean annual increment can be over 10 m^3/ha in appropriately spaced plantations between the ages of 25 and 35 years, as described earlier (site class I, site index 20 m [35].

Calabrian pine is the main forest species in Cyprus growing from sea level up to the 1600 m altitude [79]. Its forests represent about 90% of the Island's forest area, which totals at 173,182 ha [5]. Most of these forests were classified currently unexploitable after a recently carried out inventory while 41,399 ha were classified as currently exploitable [5]. Fellings are confined in the latter. The annual wood output for the periods 1988–1992, 1998–2002 and 2003–2007 was 56,100 m^3, 27,633 m^3 and 14,384 m^3, respectively [5]. This wood is utilized locally for the production of sawn timber, chipboard, box-shooks, fuelwood, charcoal and other minor wood products [79]. Sixteen thousand eight hundred thirty five hectares of the *P. brutia* forests have been selected and preliminarily classified either as National Forests Parks to provide amenities to the public, or as Nature Reserves for nature conservation [5].

The past management (silvicultural system) of pine forests in Cyprus proved to be unsuitable, resulting in serious ecological, economic and social constraints [79]. This may put in danger the survival of these stands in the long term [43]. The degradation of pine forests in Cyprus has resulted in drastic reduction of annual wood output from 56,100 m^3 (for the period 1988–1992) to 14,384 m^3 (for the period 2003–2007) [5]. The recognition of this situation and the increasing interest in using these stands for either direct production, or indirect production (environmental preservation) justifies the need for a sustainable management of Calabrian pine stands. Considering the high environmental and silvicultural variability of *P. brutia* stands [43], it is necessary to typify and characterize them in order to optimize their management.

Estimating forest productivity is both necessary for effective forest management and useful for evaluating basic site conditions for ecological field studies. Site quality is therefore influenced by factors such as available light, heat, moisture, and nutrients, along with other soil characteristics such as soil depth and aeration [29]. Although it would be best to directly measure and predict these factors, they require precise measurements that may be difficult to extrapolate across scales. Therefore, indirect methods for evaluating site quality are more frequently used in forest management [56,67,72].

Site index, defined as dominant height at some fixed base age, is one of the most commonly used indicators of site productivity because there is a close correlation between volume and dominant height growth [72]. Many mathematical functions are available to model dominant height growth. Desirable characteristics for growth functions are: polymorphism, existence of inflection point and horizontal asymptote, logical behavior, right theoretical basis, base-age invariance, and parsimony [9,14,65]. These requirements depend on both the construction method and the mathematical function used to develop the curves [65]. Among other methods for site index curve construction [38], the algebraic difference approach presents certain advantages: short observation periods can be effectively used, and the structure of equations is base-age invariant [9,14,15,42].

Modeling dominant height growth for *Pinus* sp. in the Mediterranean region has received some attention. Río and Montero [58] developed site index curves for *Pinus sylvestris* in Spain, Calama et al. [67] for *Pinus pinea* in Spain, Bravo-Oviedo et al. [2] for *Pinus pinaster* in Spain, Hatzistathis et al. [4] and Kitikidou et al. [41] for *P. brutia* in Greece.

Shater et al. [85] developed dominant height, individual-tree diameter increment, tree height, and self-thinning site curve models for *P. brutia* stands in Syria. In this work, the Chapman-Richards line was selected to show the development of dominant height on average site. Palahí et al. [57] developed and compared two sets of models (site index models for even-aged and uneven-aged stands) which enable tree-level simulation of the development of pure and mixed stands of *P. brutia* in North-eastern Greece. Adamopoulos et al. [73] examined the impact of site qualities on *P. brutia* wood characteristics in North-eastern Greece, while Kavgacı et al. [6] studied the post-fire long-term regeneration of the species in South-western Turkey through a floristic survey. Aertsen et al. [80] compared and evaluated five different modeling techniques (multiple linear regression, classification and regression trees, boosted regression trees, generalized additive models and artificial neural networks) to model site index of homogeneous stands of important tree species of Turkey (*P. brutia* among others) by using environmental variables (soil, vegetation and topographical variables) as predictors. In another study, Aertsen et al. [81] compared the performance of the same five modeling techniques for the prediction of forest site index (*P. brutia* stands among others) in two contrasting ecoregions (lowlands in Belgium and Mediterranean mountains in Turkey). Artificial neural network models have been developed to estimate volume of dominant Calabrian pine trees [49,51]. Finally, Diamantopoulou et al. [50] applied Principal Components Analysis and Hierarchical Cluster Analysis in order to interpret the behavior of several quantitative variables of reforestation Calabrian pine trees (dominant height among others).

The main goal of this study was to develop a dominant height growth model for *P. brutia* growing in two different site types in central Cyprus, from which a site quality model would be created. To achieve this objective, the variability in dominant height growth patterns and the differences among the sites were analyzed.

2. Materials and methods

2.1. Data set

The study was conducted in central Cyprus (34°56N, 33°17E), in middle elevation (300–750 m a.s.l.) forest areas. This area covers about 14,000 ha. The annual rainfall and the mean yearly temperature (for 1991–2000), according to the closest meteorological station (Kornos, 34°55N, 33°24E, 370 m a.s.l.), are 477.1 mm and 18.4 °C respectively. The geological substrate of the study area, belongs to volcanic sequence diabase dykes with pillow lava screens [30]. The soil texture is mainly sandy loam to sandy clay loam (Petrou and Milios [62], data from Forest Department of Cyprus).

The study area was formerly consisting mainly of vine and olive yards. The majority of those fields were abandoned during the last century and nowadays they have been recolonized mainly by *P. brutia* trees which is the dominant species in the area. A few olive yards are still cultivated. Moreover three built up areas are located

Table 1
Summary statistics of sampled trees per site.

Site	No. of trees	Mean *T*	SD *T*	*T* min	*T* max	Mean *H*	SD *H*	*H* min	*H* max
1	32	27.69	4.12	24	37	13.06	2.04	9.90	18.80
2	32	90.09	7.13	76	108	8.93	1.67	5.70	12.30

H (m) is total tree height at age *T* (years).

in the study area. These are the villages of Lythrodontas, Mathiatis and Kapedes.

The *P. brutia* trees form stands with different stand structures and variable densities in the wider study area. In some cases the *P. brutia* trees create small single cohort stands [18]. The *P. brutia* trees in those stands have a ground cover percentage of at least 75%, forming dense stands. Also the *P. brutia* trees can be classified to dominant, co-dominant and intermediate according to their crown class. [18,22].

Particularly the abovementioned single cohort stands are located in two different site types as regards their soil depth (site types A and B). The soil depth in the plots of site type A is over 100 cm, while the corresponding depth in the plots of site type B is about 30 cm. The soil depth was measured at 2 randomly selected points in each plot. Thirty-two plots of 100 m^2 (10 × 10 m) were randomly established in both site types (16 in site type A and 16 in site type B). From each plot one dominant and one co-dominant tree was felled, according to the stratified random sampling method, for stem analysis purposes, resulting in 64 trees (32 in each site type). From each tree, cross-sectional discs were cut and removed from the stump height (≈0 m), at breast height (1.3 m) and every 1 m, up to the bole. The last disc was collected from the 3 cm-bole diameter. In each cross-sectional disc the number of annual growth rings was counted using the LINTAB system of RinnTech and the program TSAP-Win [25]. In stem analysis for the height calculation the modified version of Carmeans' algorithm was used [40,82]. The data set was composed of 3769 recordings from the 64 sampled trees. The data summary of the sampled trees is presented in Table 1.

Data were split in two groups. The first group (80% of the trees – 2905 recordings from 51 trees) was used as fitting data, and the second group (20% of the trees – 864 recordings from 13 trees) was used as validation data. This method for testing the performance of a proposed model is known as cross-validation [21,29,52,59,60,70].

2.2. Candidate functions

An algebraic difference approach has been used, since it shows better properties and performance than analogous fixed-base-age equations [13,15]. Four models were selected from those most commonly used in forest research as candidate functions to model dominant height growth (Table 2). The first two polymorphic functions derive from the Bailey–Clutter function [66], the next two from the Korf function [78], the next is the McDill–Amateis function [55], and the final two polymorphic functions derive from the Chapman–Richards function [24].

2.3. Data structure and model fitting

To fit an algebraic difference equation expressed in the general form of $H_2 = f(H_1, T_1, T_2)$, different data structures defined in Borders et al. [8] can be used. These data structures are relevant in any increment-based modeling. The data chosen for fitting the different functions included all the possible combinations of height-total age pairs for a tree (all possible growth intervals) [8,28,39,67,74].

The fittings were carried out using the nonlinear procedure on the SPSS software [71]. The Levenberg–Marquardt iterative method was selected because it is the most useful when the parameter estimates are highly correlated [84].

The autocorrelation derived from using stem analysis data was barred by applying the Goelz and Burk [39] correction. First, each function is fitted following ordinary non-linear least squares regression and the error term e_{ij}, residual from estimating H_i using H_j, is expanded following an autoregressive process:

$$e_{ij} = \rho\varepsilon_{i-1,j} + \gamma\varepsilon_{i,j-1} + \varepsilon_{ij}$$

where: ρ = autocorrelation between the current residual and the residual from estimating H_{i-1} using H_j as a predictor variable; γ = relationship between the current residual and the residual form estimating H_i using H_{j-1} as a predictor variable; $\varepsilon_{i,j}$ = independent errors with mean zero and constant variance η^2. The model parameters are then obtained by fitting the expanded function. The autocorrelation parameters vary the weight of each observation by reducing the residual proportional to a previous residual. Neither of the autoregressive parameters ρ nor γ are used for field applications of equations because the errors $\varepsilon_{i-1,j}$ and $\varepsilon_{i,j-1}$ cannot be observed without stem analysis [72].

2.4. Model selection criteria

A three-step procedure was used to evaluate and select the most appropriate model, which included qualitative as well as quantitative examinations. The first step was to evaluate the model fitting statistics based on seven model performance evaluation criteria

Table 2
Candidate models for dominant height modeling.

Model	Name	Height–age equation	Free parameter	Difference form	
1	Bailey–Clutter [66]	$H = a_1 + a_2 T^{a_3}$	a_1	$H_2 = H_1 e^{b(T_2^{a_3} - T_1^{a_3})}$	(1.1)
			a_2	$H_2 = e^{a_1 + (\ln H_1 - a_1)(T_2/T_1)^{a_3}}$	(1.2)
2	Korf [78]	$H = a_1 e^{(a_2/T^{a_3})}$	a_2	$H_2 = a_1 (H_1/a_1)^{(T_1/T_2)^{a_3}}$	(2.1)
			a_3	$H_2 = \frac{a_1}{\sqrt[\ln T_1]{(1/a_2)^{\ln(T_2/T_1)}\ln(a_1/H_1)^{\ln T_2}}}$	(2.2)
3	McDill–Amateis [55]	$H = \frac{a_1}{1+(a_2/T^{a_3})}$	a_2	$\frac{a_1}{1-\left(1-(a_1/H_1)\right)(T_1/T_2)^{a_3}}$	(3)
4	Champan–Richards [24]	$H = a_1[1 - e^{(-a_2 T)^{a_3}}]$	a_1	$H_2 = H_1 \left(\frac{1-e^{a_2 T_2}}{1-e^{a_2 T_1}}\right)^{a_3}$	(4.1)
			a_2	$H_2 = a_1 \left\{1 - \left[1 - \left(\frac{H_1}{a_1}\right)^{(1/a_3)}\right]^{(T_2/T_1)}\right\}^{a_3}$	(4.2)

Symbols: *H* is total tree height at age *T*; H_2 and H_1 are heights at age T_2 and T_1, respectively; a_i are model parameters and *e* is the base of the natural logarithm ln.

Table 3
Model performance evaluation criteria (fitting and testing procedures).

Criterion	Symbol	Formula	Optimum value
Mean residual	MRes	$\sum_{i=1}^{n} \frac{\hat{H}_i - H_i}{n}$	0
Variance ratio	VR	$\frac{\sum_{i=1}^{n} (\hat{H}_i - \bar{\hat{H}})^2}{\sum_{i=1}^{n} (H_i - \bar{H})^2}$	1
Residual mean of squares	RMS	$\sum_{i=1}^{n} \frac{(\hat{H}_i - H_i)^2}{n-p}$	0
Absolute mean residual	AMRes	$\sum_{i=1}^{n} \frac{\lvert \hat{H}_i - H_i \rvert}{n}$	0
Coefficient of determination-model efficiency	R^2-MEf	$1 - \frac{\sum_{i=1}^{n} (\hat{H}_i - H_i)^2}{\sum_{i=1}^{n} (H_i - \bar{H})^2}$	1
Linear regression	α, β	$H_i = a + \beta \hat{H}_i + \varepsilon_i$	$\alpha = 0$, $\beta = 1$

Symbols: $\hat{H}_i$ is the ith estimated value; H_i is the ith observed value; n is the number of observations; p is the number of model parameters.

described by Amaro et al. [1] (Table 3), and select those equations who appeared to be the best.

In step two, the characterization of the model error was analyzed, based on the independent data set testing defined in Section 2.1 (864 recordings from 13 trees). For validation purposes, evaluation criteria applied in the first phase were also calculated.

Finally, the correctness of the theoretical and biological aspects of the models was assessed in step 3.

2.5. Comparison of height growth models among sites

Once the best function had been selected, the differences in the dominant height growth models for the different sites were compared using both the full and the reduced models. The reduced model corresponds to completely different sets of parameters for different sites - as these are defined from the selected function - while the full model corresponds to the same set of parameters for all the sites combined.

Two tests for detecting simultaneous homogeneity among parameters were used: the Bates and Watts non-linear extra sum of squares *F* test [74,75] and the test proposed by Lakkis and Jones, in Khattree and Naik [69], to compare the differences in site index models between sites. These tests are frequently applied to analyze differences among different regions [37,67,75].

Besides the full and reduced models, the sum of squares error (SS) is necessary to calculate both tests. This error was calculated as follows:

$$SS = \sum_{j=1}^{m} \frac{\sum_{i=1}^{n} (\hat{H}_i - H_i)^2}{n}$$

where: n = number of observations for each tree; m = total number of trees.

The *F*-test is applied using the following equation:

$$F = \frac{(SS_r - SS_f)/(df_r - df_f)}{(SS_f)/(df_f)}$$

where: SS_f and SS_r = error sum of squares for full and reduced model respectively; df_f and df_r = degrees of freedom for full and reduced model respectively. F follows an F-distribution.

Table 4
Fit statistics for each model.

Model	MRes	VR	RMS	AMRes	MEf	Linear regression	
						α	β
M1	4.0092	0.0632	25.5877	4.0092	−1.0147	2.0971	2.4969
M2	−0.0145	0.3855	7.6554	0.0145	0.3972	−0.0954	1.0153
M3	−0.0359	0.3611	7.7283	0.0359	0.3915	−0.2602	1.0421

The L statistic used in the Lakkis–Jones test is defined as:

$$L = \left(\frac{SS_f}{SS_r} \right)^{m/2} \tag{9}$$

where: SS_f and SS_r = error sum of squares for full and reduced model respectively; and m = total number of trees. If homogeneity exists among the model vectors of parameters β, the distribution of the statistic $-2\ln(L)$ converges in probability to a Pearson χ^2 distribution, with υ degrees of freedom, where υ is equal to the difference between the number of parameters estimated in the full model and the reduced models.

3. Results

Performance results of all models are shown in Table 4. All the parameter estimates for all the functions were significant at an α level of 5%, except for those of the Champan–Richards function (Model 4) which did not meet the convergence criterion. The meaning of the negative value of MEf for the Model 1 is that, the mean value of observed heights gives a better estimate than the expected values resulting from this model [1]. The Korf [78] model resulted to be the best model. Differences between M2 and M3 were very small, although the analysis of the fit statistics revealed that the Korf function generally resulted in slightly lower values for MRes, RMS and AMRes as well as higher efficiency. The shape of the curve of the Model 2 is independent of the autocorrelation correction (Fig. 1 shows both fits of M2), showing practically the same curve. Regression coefficients for M2 are calculated as:

$$H = 10.924e^{(-5.876)/(T^{0.648})}$$

$$H = 10.926e^{(-5.875)/(T^{0.647})}$$

without and with autocorrelation correction, respectively.

Table 5
Testing statistics for each model.

Model	MRes	VR	RMS	AMRes	MEf	Linear regression	
						α	β
M1	3.5235	0.0892	19.8586	3.5235	−0.8877	2.2185	2.1629
M2	−0.0015	0.4404	5.8193	0.0015	0.4468	−0.0353	1.0073
M3	−0.0092	0.4393	5.8113	0.0092	0.4476	−0.0530	1.0094

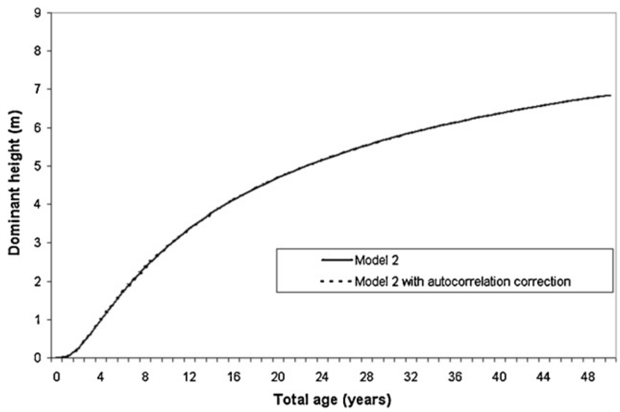

Fig. 1. Shapes of the curves of Model 2 resulting from both autocorrelation correction and not autocorrelation correction fits.

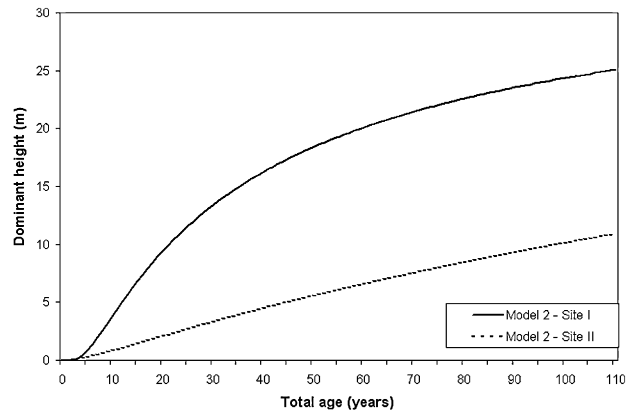

Fig. 2. Site index curves for *Pinus brutia* in central Cyprus, using the Korf function (Model 2).

The functions M2 and M3 were again those which performed better with the testing data (Table 5). Once more, Chapman–Richards function did not converged, and the Models 2 and 3 performed similarly.

The shapes of the curves of Model 2 seem to be biologically reasonable, which prevent unrealistic height predictions when extrapolating the function beyond the range of the original data. Model 2 was selected, based in the good results in the performance criteria defined in Table 3 with both fitting and testing data.

Assuming the suitability of the Model 2, it would be interesting to analyze the dominant height growth pattern among sites. Figs. 2 and 3 represent the Model 2 adjusted for each site, as these are defined from Model 2. Site I shows a very rapid dominant height growth pattern, especially for younger ages.

The non-linear extra sum of squares *F* test and the Lakkis–Jones test revealed that, the null hypothesis of parameter homogeneity was acceptable in the full model for all sites. The reduced model for site I did not converged (Table 6). On the other hand, the fit statistics obtained with full and reduced models, in all sites and sites I and II (productive and less productive) separately, were very dissimilar (Table 7). According to these results, the total model (all sites together) can be selected. In our attempt to apply the selected

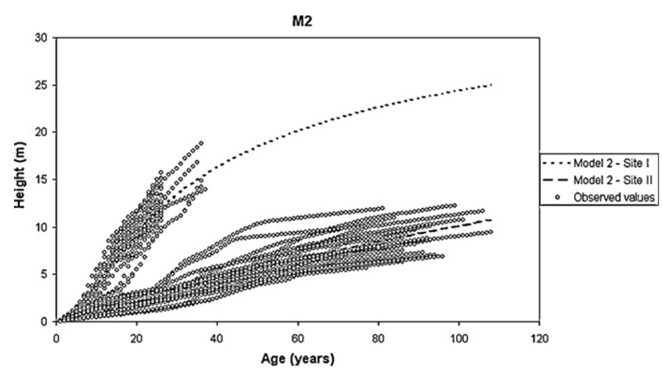

Fig. 3. Site index curves for *Pinus brutia* in central Cyprus using the Korf function together with the stem analysis.

Table 6
L and *F* statistics.

M2	*df* full model	SS_f	*df* reduced model	SS_r	Parameter *L*	Parameter *F*
All sites	2902	22216.522	2902	22216.522	1.000	0.000
Site I	Did not converged					
Site II	744	1461.900	2155	3337.704	0.0000*	0.6766

Significant *L*-values and *F*-values are marked with *.

Table 7
Fit statistics of the full and reduced models for the two sites.

M2	*N*	Model	MRes	VR	RMS	AMRes	MEf	Linear regression	
								α	β
All sites	2905	Full	−0.0145	0.3855	7.6554	0.0145	0.3972	−0.0954	1.0153
		Reduced	−0.0142	0.3855	7.6560	0.0142	0.3972	−0.0943	1.0151
Site I	747	Full	0.0333	0.9271	1.9649	0.0333	0.9035	0.1135	0.9873
		Reduced	Did not converged						
Site II	2158	Full	4.8979	0.0514	36.7628	4.8979	−0.8063	0.3312	4.1685
		Reduced	1.2765	1.2269	23.3246	1.2765	−1.4401	5.7317	−0.2036

model to sites I and II separately, the reduced model for site I did not converged, while both full and reduced model for site II gave results far beyond ideal.

4. Discussion and conclusion

Accurate estimates of forest productivity are needed for sustainable forest management in order to determine annual allowable cut and rotation period, and to make tree species selection decisions [11]. When the time needed to produce economically feasible and ecologically sustainable crops is unknown and existing growth and yield information is limited, developing site index models helps to investigate growth performance [11].

This study presents a site index model for the *P. brutia* stands in central Cyprus. The algebraic difference approach used to derive dynamic height functions of dominant trees assures a high degree of robustness in applications [15]. According to fit statistics, the growth function of Korf [78] was chosen to explain the height growth pattern of this species. The statistic criteria with testing data showed that the growth function of Korf was still the best pattern. Testing using separate intervals (sites) produced worse results that working with all possible intervals (sites), so it seems advisable to analyze all data together, especially in the testing phase, in view of the fact that the use of separate intervals is not very common in site index estimation [23].

Comparing the results of the selected model (M2) among sites, there were some differences in error measurements and model efficiency values. Similarly, parameter estimates varied considerably among sites. This could be due to little data available for an adequate estimation [16] as a result of the absence of old stands, probably because of their previous land use as vine and olive yards.

An effort was made to ensure that sampling occurred throughout the entire range of Calabrian pine stands in the study area. Within this range, it seems that an intermediate site is missing (Fig. 3). Although Calabrian pine is found in intermediate sites in the study area, the pine trees are not forming so dense stands. In this sense, the general population of pine stands was sampled, with canopy cover at least 75% of the ground, as mentioned in Section 2.1. Thus, the model that was developed provides site index estimates that will be applicable throughout most of the range of rather dense pine stands in the study area.

In spite of the apparent differences observed also in the graphical comparison of the site index curves (Figs. 2 and 3) obtained by fitting the selected function to each site, the statistical tests did not reject the null hypothesis of equality of height growth patterns.

The application of a single height growth model for all the studied area, can help us classify the quality of Calabrian pine stands and decide what measures can be taken regarding the different silvicultural treatments [37]. Nowadays, due to the state of degradation in which many of *P. brutia* stands in Cyprus have fallen [79], it is necessary to establish priority areas where resources should be invested and this site index model may provide a key tool for this purpose. A common dominant height growth model could also simplify the development of a site index model based on ecological variables [3]. Although it is sometimes necessary to stratify the study area when looking for relationships between site index and ecological variables, the analysis is facilitated with a single dominant height growth pattern [29,31].

As regards comparison of *P. brutia* growth patterns in the Mediterranean region, if the obtained curves in this work are compared with the site index model for Greek *P. brutia* stands in Thasos island [41], stands in central Cyprus show higher growth rates at younger ages and a larger gap between the best and the worst site qualities. This could be due to different soil depth of the two areas or due to different genetic background. Additionally, the large sampled area of this study and the good results obtained in different sites (fitting and testing data) makes this site index model a good option for classifying site qualities of *P. brutia* stands in Cyprus.

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